Science Council of Canada

Conseil des sciences du Canada

SECTORAL TECHNOLOGY STRATEGY SERIES

No 4

The Canadian Automotive-Vehicle Sector

SECTORAL TECHNOLOGY STRATEGY SERIES

NO. 4 THE CANADIAN AUTOMOTIVE-VEHICLE SECTOR

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Ottawa, Canada
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Catalogue No. SS25-1/4-1992E
ISBN No. 0-662-19457-8
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92-07338/

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Highlights

- The automotive sector is the world's largest manufacturing industry. In North America, the sector provides as much as 15 per cent of all employment. With 50 million vehicles produced each year, it is a major user of raw materials, and auto vehicles consume up to one-half of the entire output of oil refineries. Above all, it is an industry characterized by the generation and exploitation of new technologies. It is also one of the most fiercely competitive industries in the world.

- The principal factor shaping the international sector is the competitive success of Japanese vehicle assemblers. It is predicted that by the year 2000, Japanese automakers will dominate the international market at the expense of the Big Three U.S. automakers (General Motors, Ford, and Chrysler).

- The Canadian automotive sector consists primarily of facilities owned by subsidiaries of the Big Three. It is dominated by a few large final-assembly plants, several captive component plants, and a small and independent parts industry. The automotive-assembly and -parts sector in Canada contributes greatly to the Gross National Product (GNP), exports, and employment. In 1988, it directly accounted for $41 billion of production, $36 billion in exports, and 154 000 jobs. After the signing of the Canada-U.S. Automotive Products Trade Agreement (the Auto Pact) in 1965, Canada's share of North American vehicle production rose steadily from 7.1 per cent to 14.6 per cent in 1988. However, an attendant growth in automotive R&D and supplier activity did not occur.

- The U.S. firms are losing a large share of the domestic market to their Japanese rivals: the Big Three's share fell from 76 per cent in 1979 to 59 per cent in 1989. Japanese firms could have 37 per cent of this market by 1993.

- The success of the Japanese vehicle firms comes from their so-called "lean production" strategy — high-quality products, zero waste, multiskilled work force, and constant improvement through product R&D. Japanese automakers require 17 hours to assemble a vehicle; U.S. manufacturers need 25. Each Japanese vehicle averages only 1.2 defects; a U.S. vehicle averages 1.7. The Japanese take just 47 months and 1.7 million person-hours to develop a new model; U.S. firms need 60 months and three million person-hours. These are gaps that the Big Three are trying to close. Future competition may be based more on product than process innovation.

- Lean production also provides more flexibility in the specifications for automotive products. Within certain limitations, different models (not just different body styles of the same model) can be produced on one production line. Manufacturing processes that use computers and robots allow greater customization for individuals' needs.

- The international automotive sector is R&D-intensive: R&D expenditures by assemblers average between 2 and 6 per cent of sales. Although U.S. and Japanese firms spend about the same amount of money on R&D, the Japanese benefit more from their investments.

- Whether measured against Japan or the United States, the amount spent on automotive R&D in Canada is limited. For example, in the middle and late 1980s, research intensity (expenditures as a

percentage of sales) was a mere 0.3 per cent in Canada, compared with 3.2 per cent in the United States and 3.0 per cent in Japan. The most important European producer, West Germany, was at 3.2 per cent.

- There is some evidence that vehicle assemblers are decentralizing their R&D functions, as have other high-tech industries (such as telecommunications and computer) whose product variety specifications allow for more specialization. Local R&D can identify niche markets. In fact, a company capitalizing on creative ideas and skilled people, wherever it can find them, will probably have the competitive edge in the future.

- Are there significant opportunities for research and technological development in the Canadian automotive-vehicle sector? Building the capabilities of our contract-engineering firms would provide U.S. manufacturers with an attractive source for design R&D. Assemblers could also exploit Canadian expertise in areas such as alternative fuels to meet regional market needs and changing government regulations. Development of specialized platforms could entail the relocation of a portion of a major automaker's R&D function to Canada or a major redesign of an automobile to meet the needs of emerging foreign markets.

- Canada probably has a greater chance of obtaining R&D investment from decentralization of the Big Three than from the Japanese or European assemblers.

- If Canada is to realize any of its R&D potential in this sector, it must have more highly skilled labour, particularly in computer-aided design (CAD).

Background to the Sectoral Technology Strategy Series

In the emerging "new" economy of the 1990s, successful high-value businesses in advanced nations are being driven by innovation, propelled by spending on new products and processes. Their business strategies centre increasingly on specialized knowledge and skill in finding the right "fit" between their unique blend of core technologies and particular markets.

Where does Canada stand in this rapidly evolving new environment of changing linkages and relationships? The poor innovative capacity of Canadian industry has long been a concern of the Science Council of Canada, going back to its 1971 report *Innovation in a Cold Climate*. The Council re-emphasized this concern in 1988. It focused its attention on the potential for action at a sectoral level in its statement *A Sectoral Approach to Innovation*. It argued:

> There is growing recognition by industry and government in Canada of the key role played by technology and R&D in domestic and international competition. The Science Council considers that it is primarily the responsibility of industries to raise the degree of domestic technological sophistication and the level of R&D. Nevertheless, governments can help business to sustain long-term competitiveness both by building partnerships with individual firms and by generating consensus on the formulation of innovation strategies for the various industrial sectors. The intent is not for government to tell business what to do, but to facilitate business cooperation in a process of self-help. The process of building consensus on a strategy for a particular sector will involve close and on-going consultation with industries about the current role of technology and R&D in the sector, the opportunities foreseen, and the nature of the sources, stimuli, and forms of technological innovation. Obviously, to be successful, separate innovation strategies will be needed for each sector. The Science Council hopes that the process of building consensus will generate commitment and collective will concerning priorities, areas for cooperation, and agenda for action.

This statement proved to be an important step in the path that subsequently led the Council to undertake a major Sectoral Technology Strategy project.

In 1989, Industry, Science and Technology Canada, at a time of heightened concern for the state of Canadian competitiveness and serious questioning about the low level of Canada's gross expenditures on research and development as measured against other advanced countries, agreed to provide the main funding for this project. It also stipulated the selection of sectors on which it would like the project to focus.

Each report in this Sectoral Technology Strategy Series draws in part upon analyses commissioned by the Science Council of Canada from contractors, designed to reveal the key dynamics driving technological innovation in the sector and influencing company technology strategies. Each report has also benefited considerably from the comments and advice submitted by the many external reviewers from business, universities, and government, who are recognized in the Acknowledgements.

Commentary on the Sectoral Technology Strategy Series and R&D Targets

The Sectoral Technology Strategy Series has analysed 15 Canadian sectors. On the basis of this experience, the Science Council of Canada makes the following points with regard to Canadian R&D performance and the issue of setting sectoral R&D targets.

- Canadian firms, when grouped by sectors, generally perform much less R&D than their trade competitors. Using the indicator of R&D as a percentage of sales, Canadian firms undertake R&D at a rate about one-third to one-half the rate of their leading international sectoral competitors. The notable exception among those sectors analysed in telecommunications.

- In some product lines or specific technologies certain absolute threshold levels of R&D and capital investment must be reached if the effort is to be considered to have a chance of making a commercial payback. High thresholds are apparent in some parts of sectors such as telecommunications (central office switches), automotive parts ("Tier 1" supplier status), oil and gas (reformulated gasoline standards by refineries), and electronics (integrated circuit foundry). Such absolute thresholds cannot be clearly expressed as a percentage of sales.

- The reasons for the lower level of R&D spending by firms in most of the 15 Canadian sectors are: choice of business and technology strategy (which, in part, leave Canadian companies as essentially non-participants in many higher value-adding segments); the relatively small size of Canadian firms; the high absolute thresholds of R&D expenditure required to be a meaningful player, especially for innovative technology strategies; and the degree of foreign ownership of Canadian firms (especially important in the case of the automotive vehicles and parts sectors).

- The lack of R&D relative to other countries affects Canadian competitiveness, but it is only one of many factors, such as capital and labour costs, quality design, good marketing, and management, that interact to affect overall competitiveness. Nevertheless, the contribution of R&D, or more precisely, technology-based innovation, is becoming more pronounced throughout the global economy and Canada continues to fall behind. The low level of R&D is especially detrimental to the capacity of Canadian resource-based sectors to compete with higher-value, differentiated products, leaving them vulnerable to adverse shifts in costs beyond their control, such as a higher exchange rate.

- Major potential does exist for Canadian industry to make additional R&D investments. However, fulfilling this potential depends heavily on the vision and capability of management to make strategic use of technology, to speed the firms' innovation process, to work more closely with suppliers and "demanding customers" all the way to the end of the product chain, and to build core capabilities in incremental innovation and R&D. Canadian firms have not yet fully grasped the implications of the emerging new "lean enterprise" or "agile producer" strategy. To follow this new strategy involves seeking to offer maximum value to customers. It requires integrating the skills base of a knowledgeable workforce with flexible management structures that stimulate cooperative initiatives within and between firms to match customer needs.

- The dominant technology strategies being followed by Canadian firms in these sectors are of adopt and adapt. Innovation technology strategies are not very extensive (telecommunications is again an exception) and hardly any firms focus on breakthrough strategies to enhance competitiveness. Overall, these 15 sectors show little attempt at diversification out of existing product lines as opposed to making such products more efficiently.

- Governments can set sectoral R&D targets in the hope of stimulating enhanced industrial performance, shifts in business strategy, and greater commitment by the private sector to R&D. However, private sector R&D is only meaningfully undertaken in conjunction with a full complement of associated private and public sector actions ranging from improved design and production to finance and marketing. Doing more R&D will not be productive unless linked to a broader corporate technology strategy that is carefully designed to support the firm's business objectives. Otherwise, the corporation cannot, and will not, marshal the complementary investments required to reap the benefits of the R&D. It is the firm that must commit R&D resources.

- Setting sectoral R&D targets becomes more difficult as the boundaries between sectors are breaking down, through technological advances, regulatory change, and firm restructuring. Larger and more diversified firms that dominate modern industrial R&D perform R&D that might be allocated to any of several sectors. Examples include the textiles and materials R&D performed by large Japanese steel firms, the electronics R&D by automotive-vehicle firms, and the software R&D by telecommunications firms. Canadian governments have quite correctly encouraged higher levels of industrial R&D in Canada. In view of the rapid pace of scientific advances and technological change, plus the role of system interdependencies and synergies between technologies, setting R&D targets does not appear to be a task warranting the intensive effort, cooperation, and, ultimately, commitment that would be required by federal and provincial governments and private sector organizations.

List of Sectoral Technology Strategy Series Reports

No. 1 The Canadian Telecommunications Sector
No. 2 The Canadian Automotive-Parts Sector
No. 3 The Canadian Iron and Steel Sector
No. 4 The Canadian Automotive-Vehicle Sector
No. 5 The Canadian Oil and Gas Sector
No. 6 The Canadian Petrochemicals and Resins Sector
No. 7 The Canadian Banking Sector
No. 8 The Canadian Nonferrous-Metals Sector
No. 9 The Canadian Forest-Products Sector
No. 10 The Canadian Machinery Sector
No. 11 The Canadian Food and Beverage Sector
No. 12 The Canadian Electric-Power Sector
No. 13 The Canadian Consulting-Engineering Sector
No. 14 The Canadian Electronics Sector
No. 15 The Canadian Computer Software and Services Sector

Acknowledgements

The Science Council is pleased to acknowledge the assistance of the following people and organizations who contributed information and advice in the preparation of the report: Office for the Study of Automotive Transportation, Ann Arbor, Michigan; Maryann Keller, Managing Director, Furman-Selz, New York; Mike Dubé, Senior Policy Advisor, Ontario Ministry of Industry, Trade and Technology, Toronto; David Greeneisen, Time Engineering, Detroit; David G. Rehor, Vice President and Controller, Ford Motor Company of Canada, Oakville; Norman A. Clark, President, Motor Vehicle Manufacturers' Association, Toronto; J.A. (Joe) Pegg, Director Operations Planning and Support, General Motors of Canada Limited, Oshawa; Bernard Wolf, York University, Toronto; Slowak Skorupinski, ISTC, Ottawa; Paul Tisdall, The Network, Ottawa.

The views and conclusions in this report are strictly those of the Science Council of Canada and do not necessarily represent those of any other individual or organization.

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Introduction

An international-scale economic and industrial contest is under way. At stake is the market for the products of the world's largest industrial sector — automobiles. Canada is a major player. Yet Canada does curiously little of the design, research, advertising, and other functions of the automotive industry. Can this change? Should it? And will it? There is much at stake. Which countries will emerge winners in the future automobile market? In which functions can Canada compete?

The main objectives of this report are to indicate the technology strategies of the leading firms and compare Canadian R&D performance with that of our main trade competitors. The report also shows the major reasons for any differences and how these affect competitiveness.

Overview of the International Automotive-Vehicle Sector

The automotive sector is the world's largest manufacturing industry, producing almost 50 million vehicles each year. No other industry generates as much well-paid private employment or supports as many basic manufacturing activities. It is a bellwether industry: directly or indirectly as much as 15 per cent of all employment in North America can be traced to it. Its operations have implications far beyond production-line manufacturing.

Today's automotive industry has evolved into a technology-intensive and truly global sector. Canadian opportunities for R&D and innovation must be evaluated in the context of the evolving international sector.

The key factor shaping and driving the sector is the success of the Japanese vehicle assemblers in international markets. The relentless rise in Japan's share of the global market since the late 1960s has been phenomenal and threatens the world leadership of the Big Three automakers (General Motors, Ford, and Chrysler). Japanese automakers, as a group, will probably outsell their U.S. competitors sometime during the next decade. According to John A. Casesa of Wetheim Schroeder & Co., a U.S. investment firm, Japanese automakers will account for 40 per cent of global sales by the year 2000, up from 28 per cent today. Casesa also estimates that the U.S. share of the global market will drop from 35 per cent to 28 per cent.[1]

North America is the world's largest automobile market, accounting for 37 per cent of the world's vehicle sales.[2] An important factor in the international success of the Japanese automotive industry has been its ability to penetrate this market and to compete successfully with the U.S. industry.

Today, Japanese manufacturers account for about one-third of the North American vehicle market, with their "transplants" — cars built in North America by Japanese firms in their own factories — playing an increasingly important role. Whereas Japanese fortunes have waxed, those of North American manufacturers have waned. It is predicted that the combined market share of Japanese transplants and imports in North America will continue to rise into the mid-1990s, from 33 per cent in 1989 to 37 per cent in 1993.[3] In 1990, an economic downturn clipped Detroit nameplate sales by about 15 per cent; during the same period, offshore nameplates (virtually all Japanese) gained 1 per cent in sales.

Canadians should consider what this U.S. loss of market share does to the U.S. current-account balance, which is the difference between all U.S. export and import transactions. This turned sharply negative beginning in 1983, and the annual trade deficit has consistently been more than $100 billion. If this deficit continues, U.S. government policy is probably to change. Such policy changes — much higher tariffs on imported vehicles and much higher levels of local content for vehicles classified as domestic production — could have a major impact on Canada. Moreover, a continued deficit may indicate segments of the U.S.-based industry will leave the market. This could hurt Canada.

The bilateral automotive deficit with Japan forms a substantial portion of the total U.S. trade deficit, accounting for some 22 per cent of the net 1987 current-account deficit. The improvement in the total U.S. trade situation from 1987 to 1988 (20 per cent in the current account) was remarkably insulated from the automotive trade deficit, which improved only 3 per cent. Further substantial improvement in the overall trade position of the United States will require more balanced trade in the automotive sector. It is critical that the bilateral automotive deficit with Japan improve, since it accounts for about half of the total U.S. automotive trade deficit.[4]

According to the Office for the Study of Automotive Transportation (OSAT), University of Michigan Transportation Research Institute, there is little likelihood of this occurring. From 1983 to

1988 there was a substantial upward revaluation of the Japanese yen, but this did not moderate the sales of Japanese cars. OSAT's analysis suggests that the bilateral automotive trade deficit will at best marginally increase. OSAT's "most-probable scenario" is a 1993 constant dollar deficit 37 per cent larger than in 1988. Even a more favourable U.S. economy would reduce the deficit only marginally.[5]

OSAT's "best-case scenario" is not much better. It calls for 300 000 fewer passenger cars and 100 000 fewer light trucks to be imported from Japan. However, this reduces the value of imports of Japanese passenger cars and light trucks by only about U.S.$1 billion constant 1988 dollars because of an enriched product mix in passenger cars. In addition, increased Japanese production inside the United States, combined with the growing stock of Japanese vehicles in use, will contribute an extra $1.73 billion constant dollars because automotive parts and components will be imported. Other residual automotive products, growing at rates similar to those of the past decade, will account for an increase in the trade deficit of about $2 billion. However, U.S. exports to Japan could rise by $1.91 billion, primarily reflecting increased vehicle exports from U.S.-based Japanese plants.

OSAT's "most-probable scenario" forecasts level imports of passenger vehicles (but with a richer mix) and 100 000 additional trucks, resulting in an increase of U.S.$6 billion constant dollars. Imports of parts will increase by some $2.75 billion, reflecting less domestic sourcing by U.S.-based Japanese manufacturers but slightly higher production than OSAT's best-case scenario. The level of other automotive imports in the most-probable scenario is the same as that in the best-case scenario. U.S. exports to Japan should increase by about $1.41 billion, reflecting more realistic projections of the number of Japanese vehicles built in the United States but exported to Japan.

OSAT's analysis and projections suggest the bilateral automotive trade deficit with Japan will continue. How much that deficit grows by 1993 will depend more on automotive competition than on general economic developments. Thus, OSAT believes that the 1993 deficit, measured in constant 1988 dollars, might increase by some 37 per cent.[6]

If this scenario transpires — and preliminary 1990 evidence supports this — the United States will be unable to stabilize its current-account deficit. This is not good news for Canadian exporters in general and potential Canadian vehicle R&D in particular.

Japanese industry appears to be technologically superior in automotive products, manufacturing processes, and R&D. A major reason for the Japanese automotive industry's dramatically increased market share in North America was its ability to capitalize on the two major oil shocks of the 1970s. The Japanese were well positioned during the 1973 and 1979 oil shortages. They offered a substantial supply and an attractive range of high-quality, fuel-efficient automobiles at competitive prices when fuel prices and availability, interest rates, and a developing recession combined to shift the traditional purchasing patterns of the U.S. consumer.

For example, in 1979, the second oil shock caused the bottom to fall out of the North American light-vehicle market: sales dropped from 14.7 million in 1978 to 10.6 million in 1982. Detroit's production plummeted from 12.9 million vehicles in 1978 to a low of just less than seven million in 1982. In contrast, Japanese auto sales in North America increased 32 per cent from 1978 to 1981, just as total sales fell 23 per cent.[7]

Accompanying the Japanese automakers' rise in market share in North America during the 1980s was a fundamental shift in their strategy. First, they moved from exporting cars to the North American market to building them there; second, they began penetrating the markets for lightweight trucks (including vans and sport utility vehicles), and for mid-size and luxury cars.

This latter point is crucial, for it is from the more expensive, luxury vehicles that the Big Three derive the bulk of their profits. A recent U.S. study shows that GM obtains 61 per cent and Ford 62 per cent of their operating profits from cars selling for at least U.S.$15 000 (a representative average new car price).[8] If the new Japanese luxury-class cars, such as the Acura Legend, Toyota Lexus, and Nissan Infiniti, are successful in North America, the North American manufacturers'

market for this class of vehicle could be severely eroded. Ironically, both Japanese strategic moves were induced by import quotas the U.S. companies themselves had demanded.

The large number of Japanese auto companies (11) and the intensity of their rivalry has led to an extraordinary investment boom in North America. The assembly plants came first. During the 1980s the Japanese built 12 assembly plants, commonly called "transplants," in North America (in contrast, during the past three years U.S.-based automakers have closed eight North American assembly plants). Japanese assembly plants have been followed by engine plants and most recently by a wide variety of parts plants.

What is more, the investment flow is still broadening. The Honda Motor Company, Nissan Motor Company, and Toyota Motor Corporation have announced plans to design and engineer complete vehicles in North America by the late 1990s. With that step, they will complete the process of constructing a top-to-bottom manufacturing system. The other Japanese companies are probably to follow.

A recent major publication on the international automotive industry, *The Machine that Changed the World*, makes clear the immense impact of Japan's sales successes and new investments:

> The speed and scale of this process are truly extraordinary. Indeed, nothing like it has ever occurred in industrial history. In effect, between 1982 and 1992 the Japanese will have built in the U.S. Midwest an auto industry larger than that of Britain, Italy or Spain and almost the size of the French industry. By the late 1990s, Japanese companies will account for at least a third of North American automobile production capacity and have the ability to design and manufacture entire vehicles in a wholly foreign culture 7,000 miles from their origins.[9]

The net result, according to the *Wall Street Journal*, is that "the Japanese are taking over the American car industry, in one of history's great transfers of industrial wealth and power."[10] What is more, politics permitting, these investments will continue until the American companies revitalize their operations.

A similar pattern is emerging in Europe, where the Japanese companies are establishing assembly plants. Nissan already has an assembly plant in England, and Toyota and Honda are both building plants there. At least three Japanese assembly plants are planned for continental Europe. Using a strategy similar to their strategy in North America, the Japanese have started to produce luxury vehicles in competition with Mercedes, Bavarian Motor Works (BMW), and Jaguar. To date, however, tariff and nontariff barriers have prevented wholesale expansion of the Japanese automakers in Europe. Erosion of the European markets may occur after the Single Market program comes into effect in 1992.

In addition to the increasing Japanese share of the global vehicle market, North American and European automakers must contend with slower global market growth. Through the 1980s, indicators pointed toward maturation of the automotive market as growth slowed relative to previous decades. Greater durability of vehicles and an aging population with fewer first-time buyers have contributed to this situation. Growth in the 1990s is forecast to be within the 0.5-1.5 per cent range, down from 2-3 per cent in the 1960s and 1970s.[11]

Finally, automakers are producing more than they can sell. In addition to imports into the North American market and transplant production capacity, newer entrants, such as South Korea and Mexico, add to the growing world capacity that is rapidly surpassing probable market growth. Ford estimates that the world's automakers can build 20 per cent more cars and trucks than consumers will buy — with some 70 per cent of the excess capacity in the United States and Canada.[12]

Analysts are forecasting a shakeout in the automobile industry that will ultimately leave only four to six international automakers. This could strike a grave blow to the North American automotive industry unless it can close the competitive gap with the Japanese. The North American industry is

particularly vulnerable in the world automotive economy: unlike both Western Europe and Japan, the industry does not have major exports. Unlike Japan and parts of Europe, North America is especially open to imports. This situation and the relative importance of the North American automotive market suggest that the competition resulting from world overcapacity is probably to be most intense in North America during the next decade.

The 1965 Auto Pact and the 1989 Free Trade Agreement closely integrated the Canadian auto industry with its American counterpart. As a result, the falling fortunes of the U.S. automakers and the increasingly fierce competition they face place Canadian industry in an extremely vulnerable position. Why have the Japanese firms been able to penetrate international automotive-vehicle markets, and how does Canadian industry respond?

The Reasons for Japan's Competitive Success

The competitive success of the Japanese vehicle industry is simply due to its advantages over European and American rivals in almost every area of activity. Japanese automakers are characterized by lean management, high-quality production, zero waste, multiskilled workers, and constant improvement in product research and technology.

For example, the Japanese lead the world in efficiency at the assembly plant level. Japanese car manufacturers require an average of 17 hours per vehicle, compared with 25 hours for the U.S. automakers and 37 hours for the European ones.[13]

In terms of quality, North American and European companies have gained ground but continue to trail the Japanese. According to Harbour and Associates, a Detroit consulting firm, in 1980 each Japanese car had an average of two defects, whereas Ford's cars averaged 6.7 defects each, GM's 7.4, and Chrysler's 8.1. Today, Ford has reduced the number of defects per car to 1.5, GM to 1.7, and Chrysler to 1.8. The Japanese, however, have managed further reductions, to 1.2 per car.[14]

The cost picture is much the same. The Big Three had a $2000-per-car disadvantage a decade ago. The cost disadvantage is still between $500 and $600 per car, according to a recent study conducted by Arthur Andersen & Company.[15]

In addition, the Japanese can design, engineer, and launch new cars much faster than their rivals. Japanese automakers need just 47 months and 1.7 million person-hours to develop new products, whereas their U.S. and European competitors need 60 months and 3 million person-hours.[16]

The Japanese have also pulled ahead of competitors in product technology and development. The Japanese get more than twice the technology for every dollar invested in R&D, and take out more auto patents in the United States each year than U.S. and European car companies combined.[17]

Japanese firms have even made a major impact on Formula 1 racing, once the exclusive domain of a select handful of European manufacturers. The McLaren team, using engines supplied by Honda, have won every world championship in the past five years. These victories occurred despite a major change in race rules that prohibited turbocharged engines. McLaren's Honda engines won almost every race when turbochargers were paramount, and they continued to win when standards effected a return to conventionally aspirated engines. This demonstrates that the Japanese industry offers not only value-for-money technology, but also the best technology by absolute standards.

Japanese vehicles have shown constant improvement over the last 10-15 years. A unique and noteworthy index of quality is the consumer survey. In the 1980 annual auto issue of *Consumer Reports*, for example, the Honda Civic — a very popular model introduced in 1974 — enjoyed only an average ranking in terms of repair problems over six years. In fact, 1975 Civics were rated a little worse than average. But in the 1990 issue the Honda Civic was uniformly rated "much better than average" for all of the previous six years. The index of perceived quality among Toyota owners

followed a similar pattern. Back in 1972 and 1973, Toyotas showed signs of some problem areas, specifically engines. By 1980 the problems had gone. In 1990 virtually all Toyota cars were ranked "much better than average" in six years of operation.[18]

American cars have improved greatly over the past decade. As Figure 1 illustrates, average problem rates reported for new U.S. cars declined by about 66 per cent between 1980 and 1990.[19] Nonetheless, the reliability of new American models is only now comparable to the average of new Japanese models a decade ago.

Japan's advantage with respect to older cars is less clear. Figure 2 indicates that the average problem rate for five-year-old U.S. models dropped 36 per cent between 1980 and 1990. Although a large gap in reliability remains between Japanese and U.S. models, American automakers, as a group, have achieved a steadier growth in improvements than their Japanese rivals in the most recent five years. Detroit may be behind, but it is not necessarily out of the race.[20]

Even more alarming for Detroit and European producers is the recent introduction of new up-market luxury and sports cars by Japanese firms. For example, both consumer magazines and the car enthusiasts' press have described the new Toyota Lexus LS400 as a benchmark in total automotive-product quality.[21] The Infiniti Q45, produced by Nissan, gets comparable reviews.[22] Rarely have such two completely different perspectives for evaluating automobiles coincided. Consumer advocates laud their comfort and evident construction quality; enthusiasts applaud their performance.

Not only is Detroit in trouble, but European producers such as BMW and Mercedes-Benz are being threatened. *Consumer Reports* recently compared the two new Japanese luxury cars with German and American models of reputed quality and performance. The magazine, with some qualifications, indicated that the Japanese cars were the new benchmarks for value.[23]

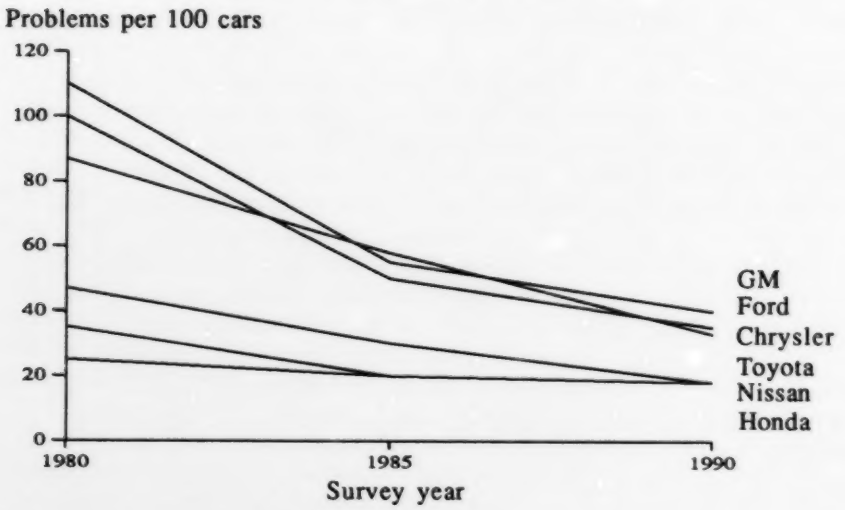
The most important factor contributing to Japanese success is the way in which the Japanese automotive industry is organized and managed. There is now a consensus that the Japanese selectively adopted technologies from Europe and North America and incorporated them into a production system designed to meet the needs of their targeted markets. This in turn led to a superior means of organizing and managing an auto industry that would provide sustainable competitive advantages in the international marketplace. As a noteworthy Canadian study says, "Their system emphasizes teamwork, continuous improvement, the elimination of waste, and the relentless pursuit of quality as defined by value to the customer."[24]

The Massachusetts Institute of Technology (MIT) recently completed a $5 million, five-year study of the world automotive industry. The study's conclusion is that the Japanese auto industry has created a fundamentally new approach to manufacturing and with it a new industrial revolution. According to the study, the new manufacturing system, which the authors call "lean production" or the "lean enterprise," is centred in the auto industry, but it has ramifications in virtually all industrial sectors in the world. Indeed, the report predicts that "lean production will supplant both mass production and the remaining outposts of craft production in all areas of industrial endeavour to become the standard global production system of the twenty-first century."[25]

The lean enterprise encompasses not only a production system but also R&D, supply, and distribution. Its effect is not limited to automobiles. Its impact will be felt throughout manufacturing and perhaps even in raw-materials processing.

Figure 1. Quality of new cars

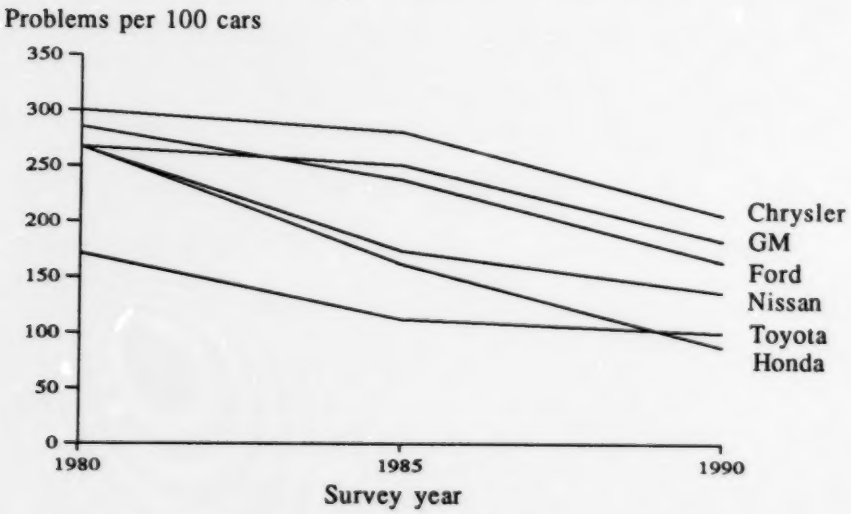
(Cars new when surveyed)



Source: *Consumer Reports* (April 1991)

Figure 2. Reliability of old cars

(Cars five years old when surveyed)



Source: *Consumer Reports* (April 1991)

The Lean Enterprise

Lean Production

A useful way of characterizing lean production is to contrast it with craft production and mass production, the two earlier production systems.

The craft producer uses skilled workers and simple but flexible tools to make custom-designed products one item at a time. Goods produced by the craft method — as automobiles once were — are too costly for most people. Shortly after World War I, however, Henry Ford and General Motors' Alfred Sloan moved world manufacture away from craft production and into the age of mass production. Mass production was developed to satisfy the needs of a mass market, and, largely as a result of the success of this method, the United States soon dominated the global economy.

In mass production, muscle power is clearly separated from brain power. The mass-producer uses skilled, highly specialized professionals to design products to be made by unskilled or semiskilled workers, often tending expensive, single-purpose machines. Jobs are broken down into small, easy-to-master steps, permitting the employment of inexperienced workers. Rigid job classifications and work rules create a clear distinction between the respective rights and responsibilities of labour and management. Labour is responsible for performing specific manual tasks, and management is responsible for overall coordination and for identifying and solving problems.

Mass production churns out standardized products at a very high volume. Because the machinery costs so much and is so intolerant of disruption, the mass-producer adds buffers — extra supplies, extra workers, and extra space — to ensure smooth production. Since changing to a new product involves greater costs, the mass-producer keeps standard designs in production for as long as possible. The result is that the consumer gets goods that are less expensive, but variety and innovation are sacrificed.

After World War II, the Toyota Motor Company in Japan pioneered the concept of lean production. The rise of Japan to economic pre-eminence quickly followed as other Japanese companies and industries copied this remarkable system.

The lean producer, in contrast to the mass-producer, combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter. Toward this end, lean producers employ teams of multiskilled workers at all levels of the organization and use highly flexible and increasingly automated machines to produce volumes of products in enormous variety.

The major implication of lean production is that it is possible both to attain economies of scale and to offer variety.

A rule of thumb in the automotive sector is that any given production line or facility should be capable of producing 250 000 units (cars) annually. At this rate, virtually all economies of scale are exhausted. Obviously this creates problems if any given model cannot attain this level of annual sales. For example, this was the problem Ford faced with its luxury Lincoln offerings. Whereas GM's Cadillac has sold more than 200 000 units annually since about 1964, the Lincoln never achieved similar sales. The Lincoln often had to share production facilities with other Ford products. In turn this constrained body styles, optional accessories, design, and so on, all of which further limited sales prospects. In sum, each production line could produce only one model.

But with lean production this is no longer true. For example, up to four different models, each with one of two possible body styles, can appear from one line in a lean-production environment. Each style can be made economically in small numbers, for example, 40 000 units. This is a revolutionary step. And the trend will continue. It will allow greater and greater product variety — and also greater opportunity for creativity in niche design and marketing.

Lean production is "lean" because it uses less of everything than mass production: half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. In addition, lean production requires far less than half the parts inventory on site, results in fewer defects, and, as already mentioned, produces an ever-growing variety of products.

The work team is the heart of the lean factory. To produce in small lots, it is more effective to organize workers in small teams of multiskilled workers that can be redeployed as necessary. The team concept is also the building block for quality circles, in which workers identify the root causes of production problems. Work teams prevent defective work from entering the next stage of production; this differs from the procedure in mass production, in which quality is inspected after production has been completed.

However, building these efficient teams is not simple. First, workers have to be taught many skills — in fact, all the jobs in their work group — so that tasks can be rotated and workers can fill in for one another. Workers then need to acquire many additional skills, such as simple machine repair, quality checking, housekeeping, and materials ordering. Finally, they need encouragement to think actively, indeed "proactively," so they can devise solutions before problems become serious.[26]

By contrast, Detroit traditionally managed by numbers and hierarchy. Maryann Keller documents this practice at General Motors (typical of Detroit practice) in her book *Rude Awakening*:

> Missing from the power equation are the production engineers, who perform critical functions in the plant, and set out the manufacturing systems by which parts and cars are made. General Motors, like most of American industry, has accorded little status to the very people who are responsible for the hands-on creation of the product. Nor has there been status given to the marketing people, a possible factor in GM's failure to understand and address the needs of the changing marketplace.
>
> Such narrow role definitions were not always the rule at GM, and the finance staff has not always dominated policy. At one time (often referred to by retired GMers as the "pre-Donner days"), the general managers of car divisions were well-rounded executives who had some responsibility for design, styling, engineering, manufacturing, and marketing the cars they sold. The only thing they didn't do was control the finances of the operation. This was done by a comptroller who reported to the central office. His function was simply to oversee the profit and loss — not to pass judgement over the direction of the operation. But in recent decades, as GM's CEO has become more remote from company operations, the finance staff has emerged as something akin to his personal CIA. In the process, the powers that be at the company have learned to trust the insiders on the finance staff more than the operations people.
>
> Sadly, the priorities often get scrambled when GM attempts to measure the value of its career professionals — a fact that is common in other auto companies, as well. For example, a topnotch drive train engineer is clearly of great worth to the company, but he is not compensated — either financially or with prestige — for his technical excellence. Rather, if he has any hope of earning good money, he must, by the time he is in his mid-thirties, become a manager. Apart from the fact that engineering talent does not necessarily translate into managerial talent and may result in a loss of technical talent for the company, the management track also involves a rapid turnover of jobs every two years. The intention is to give the manager broad exposure in the company. But the end result is that it fosters an environment where no one is responsible for or accountable to a project from start to finish.[27]

Instead of efficiency, the system produced paralysis. To be sure, this is changing. All of the Detroit assemblers have made major investments in more modern and flexible production systems. But they are still not at Japanese levels.

In conclusion, the Japanese define quality as value to the customer and make it their paramount goal. They maximize quality and productivity by continually refining all processes, thus improving the total *system*. Process improvements that lead to higher quality are also probably to yield lower costs, shorter production cycles, and faster, cheaper, and more customer-focused product development.

Lean R&D

In addition to its use in manufacturing, the lean approach has been applied by Japanese automakers equally successfully to new product development.

The integration of design and development with manufacturing operations has long been problematic in traditional mass production. In mass production, design and manufacturing decisions typically proceed as separate activities that come together shortly before production begins. Designers are often pictured as working for years on blueprints and then "tossing them over a wall" to manufacturing just before the production launch date. Manufacturing engineers complain that vehicles are designed in ways that make them if not impossible to manufacture, then at least difficult to manufacture within quality and cost constraints. A high proportion of vehicle-quality problems reportedly arise from design errors, and these problems become more costly as their detection occurs further along the production cycle.

In fact, when 15-25 per cent of development is completed, 75 per cent of production costs have been committed.[28] Thus, designers spend substantially less than half the total product cost, but they commit well over half those costs. In mass production, designers often make fundamental decisions without being aware of the downstream effects of their decisions on, for example, the product's manufacturability or marketability.[29]

The difficulties inherent in mass production's separation of R&D from manufacturing can be traced to the origins of mass production. In thinking about innovation, Sloan carried Henry Ford's ideas on the division of labour to their logical extreme. He concentrated the scientists and engineers who were working on advanced preproduction ideas at GM's technical centre outside Detroit. There, he felt, they would be free of the daily distractions of commerce and better able to focus on the company's long-term needs. Over the decades, GM built an enormous and very high-quality staff who made several fundamental discoveries. Unfortunately, new ideas percolated from the research centre to the market very slowly.

In contrast, the Japanese lean producers are extremely careful not to isolate their advanced technologies from the day-to-day workings of the company and the incessant demands of the market. Based on their observations of the U.S. and European mass-producers, they long ago concluded that to be effective even the most advanced engineering must be tied to the key market-driven activities of the company.

Given their contrasting approaches to innovation, it is not surprising that Japanese and North American styles of technological development differ so dramatically. In particular, it is not surprising that the U.S. companies spend more on their research but badly trail the Japanese companies in key indicators of technological strength such as patenting or product lead time.[30] For example, the Japanese spend an average of 1.7 million engineering hours on each new platform, compared with 3.0 million in Europe and 3.1 million in North America. Die lead time is 13.8 months in Japan, 26.8 months in the United States.[31]

These differences reflect fundamental differences in organization and management. The key to Japanese success in translating R&D expenditures into patents and commercial advantage lies in the

organization of R&D. The lean-development system, now being adopted by GM, Ford, and Chrysler, is an integrated or overlapping process using multidisciplinary teams and simultaneous engineering to develop products. A team comprising all elements of the organization (design, manufacturing, marketing, etc.) is responsible for vehicle design and engineering. The team minimizes production problems by designing for manufacturability.

The lean-development process is very similar to the lean manufacturing used in the assembly plant. Unlike the mass-producer, who keeps the line moving at all costs and ends up redoing huge amounts of work at the end, the lean producer spends more effort correcting problems before they multiply. As a result, the lean producer spends less effort for higher-quality results.

Simultaneous engineering has profound implications for assemblers and suppliers. If North American assemblers are to match the Japanese, product design must occur closer to the place of manufacture, integrating product and process engineering. Suppliers must participate in the design process from the concept stage, working with both the platform team and the central engineering staff.[32]

Lean design and development provide companies with enormous competitive advantages. Such companies can offer a wider variety of products and replace them more frequently than their mass-production competitors. And this is exactly what occurred throughout the auto sector during the 1980s.

The trend is striking and continuing. Japanese firms are using their advantage in lean production to expand their product range rapidly, even as they renew existing products every four years. Between 1982 and 1990, the firms nearly doubled their product portfolio from 47 to 84 models. Moreover, the lean approach makes design and development subject to the same principles of continual improvement as are employed in manufacturing. For example, Mazda has set a target of a fourfold increase in product-development productivity in the next 10 years. This means it will try to design twice as many cars in half the time without any additional staff.

During the 1980s, Japan's auto sector was perfecting lean development, whereas the European firms were pursuing old-fashioned mass-production strategies. The Europeans reduced their offerings from 49 to 43 models, and the remaining products aged markedly.

The Americans, in contrast, have increased their product ranges substantially, from 36 to 53 models, but at a cost of longer model cycles. A typical Japanese product has been in production between 1.5 and 2.0 years — about what one would expect from companies with policies of replacing every model every four years. In North America, the mean age has risen from 2.7 to 4.7 years. This suggests that the average model remains in production for nearly 10 years — as opposed to the eight years that was common in the past. The reason seems to be that American manufacturers, with their inefficient product-development processes, are incapable of simultaneously expanding their product range and renewing their products frequently.

Because it delivers better products more cost effectively, lean development has fundamentally changed the nature of competition in the auto industry. The producers who have fully mastered these techniques can use the same development budget to offer a wider range of products and shorter model cycles or, alternatively, to develop new technologies. It is probable that lean development is the function in which the Japanese assemblers are furthest ahead.

Lean Supply

A typical modern car has more than 10 000 parts. Organizing the design and manufacture of these parts is probably the greatest challenge in producing a motor vehicle.

The history of parts supply to the Big Three auto assemblers has shifted between two extremes: parts were supplied in-house by the auto assembler itself, or parts were supplied to the assembler by independent companies through bids. In the 1980s, the Big Three were using both

approaches. GM was the most integrated, with about 70 per cent of the parts in each of its cars and trucks supplied by an in-house parts division. Ford and Chrysler relied more on outside suppliers.

Japan's auto industry has pioneered a new lean approach that allows an assembler to deal more effectively with its supplier base. Japanese assemblers use tiered supply structures in which only a fraction of the supply base — Tier 1 suppliers — deals directly with the vehicle maker. In turn, Tier 2 and Tier 3 level firms supply components and small assemblies to the Tier 1 firms. This leaves the automaker free to concentrate on overall product development and final assembly.

In the lean-supply system, each level of the supply structure is defined by the breadth and degree of its product and engineering responsibility. Tier 1 suppliers are usually large, technologically sophisticated companies that play a major role in product development and subassembly. They supply the assembler directly. Tier 1 and Tier 2 suppliers must have in-house manufacturing and design-engineering.

The leading Japanese lean producers use fewer than 300 suppliers in each project (compared with 1000 to 2500 for mass-producers in the West). These suppliers are usually the companies that supply the same parts for the producer's other models and are long-term members of the assembler's supplier group.

The tiered supply structure has helped the Japanese greatly reduce product-development times and costs. Because lean producers are so successful in devolving much of the responsibility for engineering and parts manufacture to suppliers, they do much less themselves than do mass-production companies. Of the aggregate cost of the materials, tools, and finished parts needed to make a car, the Toyota Motor Corporation itself accounts for only 27 per cent. The company produces four million vehicles a year with only 37 000 employees. General Motors, in contrast, adds 70 per cent of the value to eight million vehicles and needs 850 000 employees worldwide to do it.[33]

Admittedly, Toyota's efficiency in everything it does accounts for part of the difference. A large part of the difference, however, is that Toyota and other lean producers do fewer things. For example, Japanese lean producers do detail engineering on only 30 per cent of the parts in their cars (detail engineering is the process of producing detailed drawings of parts that suppliers can then use to make the parts). The suppliers engineer the rest. During the early 1980s, in contrast, the American mass-producers did detail engineering on 81 per cent of their parts.[34] Thus the R&D activities of the assemblers only are not the whole story. The Japanese firms capitalize on the R&D innovations of their supplier firms — in effect they have partially decentralized their R&D. (See Science Council of Canada Sectoral Technology Strategy Series, No. 2: *The Canadian Automotive-Parts Sector*.)

The relationship between suppliers and assemblers in mass production is largely adversarial, whereas in lean production it is cooperative. Suppliers to mass-producers are selected by bids in which cost is paramount. Suppliers to lean producers are selected on past relationships and proven performance.

In the mid-1980s, the Big Three experimented with reducing the fraction of parts they obtained from their in-house suppliers. This tactic was inspired by a belief that the lower wages of outside supplier companies were the competitive secret of Japanese supply systems. According to the authors of the MIT study, this change in direction — now on hold at Chrysler and GM because of resistance by middle management and the United Auto Workers (UAW) — largely misses the point. The key to a competitive parts-supply system is the way the assembler works with its suppliers; whether the supplier is in-house or fully independent has no bearing on the issue.[35]

Lean producers and suppliers operate in a different framework. The efforts of both parties are mutually beneficial, with minimum wasted effort. By abandoning power-based bargaining and by jointly analysing costs, determining prices, and sharing profits, producers and suppliers are not in an adversarial relationship but in a cooperative one. The result is lean supply.[36]

Lean Distribution

Certain elements in the distribution system of the Japanese automobile industry will probably never be copied in North America or Europe — for example, the Japanese tradition of door-to-door sales of automobiles. Nevertheless, the lean approach to dealing with customers is an integral part of lean enterprise, and many aspects of the Japanese lean-distribution system have proven successful in the West.

First and foremost, the Japanese system builds customer loyalty through quality products and after-sales services. The companies go to extraordinary lengths not to lose a customer once he or she is in the fold, and consequently it is difficult for new competitors to gain market share.

The Japanese dealership system is much more concentrated than the North American one: there are only 1621 dealer firms in Japan, compared with some 16 300 dealer principals in the United States. Lean producers not only have a limited number of suppliers, but they also work with a limited number of dealers, who together form an integrated part of their lean-production system.[37]

Japanese distributors periodically survey almost all consumers in the Japanese market. This is the first step in the product-development process and avoids the need for the time-consuming, expensive, and frequently inaccurate market-assessment surveys employed by mass-producers in the West. Moreover, because it is constantly in touch with consumers, the Japanese lean-distribution system helps fine-tune new products and catch embarrassing or dangerous errors before massive and highly visible recalls are needed.

The lean-selling system also reduces inventory costs dramatically and smooths the flow of production from factory to consumer. The whole distribution system contains only three weeks' supply of finished units, most of which are already sold. Lean production achieves its highest efficiency, quality, and flexibility when all activities from design to assembly occur in the same place. The final step in the system, lean sales and service, cannot work without a production system located in the same area as the sales market.

For this reason, lean producers in the 1990s will need to create paper-concept to finished-car manufacturing systems in the three great auto markets of the world — North America, Europe, and East Asia (centred on Japan). This process is furthest along in North America, where the geographic pattern of lean production is already evident. Honda, Toyota, Nissan, Mazda, and Mitsubishi have also all established North American product- and process-engineering operations. Honda has an engineering centre at its Marysville, Ohio, complex, Nissan is in Tennessee, and the others are in the Detroit area. Their rationale is self-evident: they want to be close to the headquarters of U.S. suppliers and to recruit engineers easily in Detroit. Most of their supplier plants, some old and some new, are nearby so that the assembler can get parts in less than a day.

At first, the vehicles assembled in these plants had only about 20 per cent U.S. and Canadian content. By 1990, however, this figure reached about 60 per cent, and it is expected to rise to 75 per cent by the late 1990s.

Although the Japanese advance in Europe has been much slower, it is anticipated that by the end of the 1990s several Japanese assemblers will have top-to-bottom production systems in place on the continent.

R&D in the International Automotive Sector

Globally, the automotive industry is an R&D-intensive sector, with expenditures by assemblers averaging 3-6 per cent of sales. The relatively high level of activity in the sector is demonstrated by the Big Three's R&D expenditures, which in 1987 totalled almost U.S.$8 billion.[38] Of this amount, GM spent $4.36 billion, Ford $2.5 billion, and Chrysler $798 million, placing them first, second, and twelfth respectively, in rankings of private research conducted by U.S. companies.[39]

The largest motor-vehicle industry in the world is Japan's. The U.S. National Science Foundation (NSF) reports that in 1985 the Japanese vehicle industry spent $3.2 billion (1982 dollars) on R&D, or 3.0 per cent of sales. Surprisingly, this total was below the U.S.$5.5 billion (1982 dollars) for the U.S. vehicle industry, or 3.2 per cent of sales. These figures can be misleading, however. Within a year and a half of this comparison period, the U.S. dollar had fallen by about 45 per cent against the yen, and it could be argued that spending on automotive R&D by Japan now exceeds or matches that of the U.S. industry in terms of the current devalued dollar. Moreover, the amount Japan spent on automotive R&D was rising throughout the early 1980s. In 1980 it was only 2.3 per cent of sales. In any event, R&D funding levels that are this close indicate little about the competitive effectiveness of such activities. Several studies, however, indicate Japan has a considerable advantage in design productivity over the United States.[40]

The rise in Japan's spending on automotive R&D is a powerful example of a more general trend. The growth in Japanese industrial R&D spending has been well-discussed among its international competitors for several years. Japan surpassed the United States in total R&D spending as a proportion of GNP in 1985 and 1986. More importantly, Japan has surpassed the United States in nondefence R&D expenditures as a proportion of GNP for the last two decades (for example, 2.8 per cent of Japan's GNP compared with 1.9 per cent of the United States' GNP in 1985). Moreover, the government of Japan spent U.S.$7.6 billion (1982 dollars) on R&D in 1985; the U.S. government spent $46.0 billion in the same year. No less than 72 per cent of the U.S. expenditures were committed to defence and space, which may have only limited commercial pay-off, compared with only 11 per cent for Japanese government R&D. The U.S. federal expenditures on nondefence R&D amounted to U.S.$12.9 billion compared with U.S.$6.3 billion that the Japanese government spent in 1985.[41] A subsequent dollar devaluation results in two approximately similar sums — a striking development because Japan has roughly half the population of the United States. To put this in perspective, nondefence R&D funded by the Japanese government is twice the level of total industrial R&D funding in Canada in 1985. Thus, the growth of automotive R&D in Japan is typical of the growth of all Japanese industrial R&D.

Moreover, apart from increased expenditures, what is most worrying to their competitors is the ability of Japanese companies to maximize benefits from their R&D investments. Although Japan's R&D activities initially absorbed European and American technology, the Japanese are now at the leading edge of automotive technology. Toyota, Nissan, and Honda now have more patents granted in the United States than GM and Ford. Japan leads in patents related to engines and automotive electronics, whereas Europeans lead in those related to brakes, clutches, and process equipment. The Americans hold their own with the Japanese and Europeans only in patents related to motor-vehicle bodies.[42] Japan may well be pulling ahead of the United States in absolute terms in new industrial technology.

In sum, with a lean-development system, the Japanese have been more successful than their competitors in turning R&D expenditures into innovative products and processes. As a result, the automobile industry is becoming more R&D-intensive, with greater value added as a result of R&D

activities. The pace of technological change will continue. Vehicles of the 1990s will be constructed of advanced composites and incorporate up to $2000 of electronics that perform functions such as emission control, antilock braking, and active suspension.

Canada's Role in the International Automotive-Vehicle Sector

Canada's automotive industry has been dominated by U.S. firms since the Ford Motor Company established a manufacturing branch in Windsor, Ontario, in 1904. In 1965, the Canada-United States Automotive Products Trade Agreement, commonly known as the Auto Pact, fused Canadian and U.S. assembly operations. The Auto Pact allowed the integration of production and marketing in North America by abolishing tariffs on assembled vehicles and original equipment (OE) parts. Thus, Canadian vehicle-assembly and parts plants secured access to the U.S. market. Canadian plants were managed in the same way as U.S. plants, and the same union represented workers in both countries.

Although the Auto Pact allowed free trade in assembled vehicles and OE parts for qualified manufacturers, it did not cover aftermarket parts. The Canada-United States Free Trade Agreement addresses this situation: it removes all tariffs on aftermarket parts by 1994.

As already mentioned, the Auto Pact led to close integration of the Canadian and U.S. automotive producers and markets. The auto-vehicle sector in Canada today consists primarily of facilities owned by Canadian subsidiaries of the U.S. Big Three. Most of these facilities are final-assembly operations for passenger cars, vans, and light-duty trucks, and much of their production is aimed at the U.S. market.

Mainly because of the Auto Pact, the Canadian share of North American vehicle production grew from 7.1 per cent in 1965 to 14.6 per cent in 1988. Canada's annual output in the same period grew from 846 000 to 1 977 000 units. Some industry observers expect Canada's share to continue to grow in the coming years, reaching 18-20 per cent by the mid-1990s. Canada's share of North American parts production also increased from 9.8 per cent in 1982 to 13.1 per cent in 1986.[43]

The automotive-assembly and parts sectors are major contributors to GNP, exports, and employment in Canada, accounting for $41 billion of production (vehicle production of $27 billion, parts production of $14 billion), exports of $36 billion, a positive trade balance of $4 billion, and 154 000 jobs (1988 data). Automotive activities accounted for about 16 per cent of total Canadian shipments of manufactured products in 1986 and 44 per cent of manufactured exports to the United States.[44]

Despite Canada's increasing share of North American production, the growth in sales of overseas-built cars in Canada and the United States has tended to depress the rate of growth of North American production as a whole since the late 1960s. The erosion of the market share of vehicles built in North America is only being stemmed by the establishment of transplants in Canada and the United States.

As in the United States, foreign assemblers, particularly the Japanese, continue to increase their share of the Canadian market at the expense of the Big Three. In 1990, foreign companies enlarged their light-vehicle sales in Canada by 5 per cent, whereas the total market dropped 11 per cent, and sales of the Big Three plummeted 16 per cent. Overseas assemblers built 37 per cent of the cars sold in Canada in 1990 and 30 per cent of all light vehicles.[45]

Four such facilities — Honda in Alliston, Ontario; Toyota in Cambridge, Ontario; General Motors-Suzuki (CAMI Automotive) in Ingersoll, Ontario; and Hyundai in Bromont, Quebec — operate in Canada. These facilities represent investments of more than $1.6 billion and have a production capacity of more than 430 000 units per year. As a result, Canada has roughly 17 per cent of the Japanese transplant-assembly capacity in North America.

New investment in Canada has been directed both to Asian-owned transplant facilities making vehicles and parts and to domestic manufacturers for plant modernizations. The number of

foreign-owned (either wholly owned by the Asian vehicle companies or independent) and joint-venture parts facilities has also grown rapidly in recent years, with total investments in the hundreds of millions of dollars. In addition, GM, Ford, and Chrysler have made comparable investments in Canada. GM's expansion of its Oshawa complex is expected to cost $8 billion over the next 10 years.

The importance of Canadian assemblers in the North American automotive sector has increased for several reasons, including competitive Canadian exchange rates (until recently), competitive wages, lower costs for benefits (in part because of government health insurance), and a quality-conscious work force.

Some of Canada's competitive edge in attracting production facilities and investment in the automotive sector, however, is threatened by the escalating Canadian dollar relative to its U.S. counterpart. Industry representatives believe that a U.S.$0.85 exchange rate is critical for Canadian competitiveness.[46] In recent months, however, the Canadian dollar has been trading above U.S.$0.86.

R&D in the Canadian and U.S. Automotive Sector

Canada has two major interests in obtaining automotive R&D work. First, such work might provide a more independent foundation for growth in Canada's automotive sector and an allure for the further expansion of R&D. This will become increasingly important as other auto-producing countries improve their products and Canada's relative advantages narrow.[47] Second, by providing well-paying, skilled employment, R&D offers direct economic benefits.

There is an important role for R&D and potentially much to be done with it in the automotive sector. At least 25 major automotive producers now compete in many regions for sales. Their competition is fiercest in the lucrative and largest regional market, North America (United States and Canada). This market accounts for 37 per cent of the world's vehicle sales. Recently, the competitors have directed the consumer's attention to the differences in their products. Competitive products are possible only if R&D activities promote innovation and manufacturing efficiency. Research and innovation should accelerate because of remaining differences among the major regional markets for motor vehicles and among manufacturing methods of firms.

R&D should also increase in response to new regulations for vehicle safety, emissions, alternative fuels, and fuel economy. Once again, firms face twin challenges: first, performance, quality, styling, and price demanded by consumers; second, safety and environmental protection demanded by government regulations. This apparent dilemma is exacerbated for motor-vehicle manufacturers by the different regional requirements for emissions, safety, and fuel economy.

A more direct outcome of the Japanese challenge in the automotive market has been a strategic reconsideration of R&D at the Big Three. This reconsideration has focused on what units or companies should perform R&D activity, and where. In particular, the second half of the 1980s witnessed efforts to "outsource" engineering work — to have it performed by parts suppliers and by specialized engineering services (ES). At the same time, purchases of parts were "re-sourced" away from traditional U.S. and Canadian suppliers, not only to Mexico, but also to producers outside North America. This step was taken to save money. Accordingly, some similar re-sourcing of R&D work has developed, and more might develop in the future.

Before we address the questions of what Canada is doing in automotive R&D and what could be done, we must define the term "research and development."

Work conducted for the Science Council of Canada by OSAT made considerable use of NSF data. The NSF provides standard definitions, which it uses in its annual surveys of U.S. industrial R&D:

> **Research and development** — Basic and applied research in the sciences and engineering and *the design and development of prototypes and processes*. This definition excludes quality control, routine product testing, market research, sales promotion, sales service, research in the social sciences or psychology, and other nontechnological activities or routine technical services.

The NSF has three classifications for industrial R&D:

> **Basic research** — Original investigations for the advancement of scientific knowledge not having specific immediate commercial objectives, although such investigations may be in fields of present or potential interest to the reporting company.
>
> **Applied research** — Investigations directed to the discovery of new scientific knowledge having specific commercial objectives with *respect to products or processes*. This definition differs from that of basic research chiefly in terms of the objectives of the reporting company.

Development — Technical activities of a nonroutine nature concerned with translating research findings or other scientific knowledge into *products or processes*. Not included are routine technical services to customers or activities excluded from the foregoing definition of R&D.[48]

The above definitions make certain that almost any expenditure to develop products or processes qualifies as R&D, either as applied research or as development. Expenditures on styling changes or similar minor refinements to current products also generally qualify as industrial R&D. The NSF survey, for example, reported U.S.$58.85 billion of company-funded industrial R&D spending in the United States in 1986. Development expenditures amounted to $38.88 billion (74 per cent), and basic research constituted $2.09 billion (3.6 per cent) of total R&D spending.[49]

The NSF industrial survey concentrates on the measurement of R&D performed by U.S.-based companies. R&D funds spent by contractors or outside of the United States are measured separately and not well reported. This often leads to varying degrees of discrepancy between the NSF survey-based approximations of industry group R&D levels and those estimated by other organizations based on alternative sources.

This is certainly the case for manufacturers of motor vehicles and equipment. *BusinessWeek* recently created a composite of R&D spending by 25 U.S. automotive firms. Of a total of U.S.$10.3 billion spent in 1989 (up 9 per cent from 1988), about $9.5 billion (92 per cent) was reported by the seven U.S. producers of original equipment (OE). The remaining $0.8 billion was reported by 18 large automotive suppliers.[50] In contrast, the NSF recently estimated that the U.S. motor-vehicle industry spent U.S.$7.5 billion of company funds on R&D in 1989, a 3.8 per cent decrease from the previous year. In 1987, the NSF reported that the four largest performers of R&D in the motor-vehicle industry accounted for 94 per cent of the $7.3 billion in R&D spending that year.[51]

The *BusinessWeek* data are taken from the Compustat financial services program, which contains corporate responses required by the U.S. Securities and Exchange Commission (SEC). The SEC does not limit the reporting of corporate R&D funding to expenses in the United States or to in-house activities. It is obvious that *BusinessWeek* overestimates U.S.-located spending on automotive R&D in the United States because it includes expenditures made overseas. It is equally evident that it underestimates total automotive R&D spent worldwide by U.S. companies, since it reports on an industry composite of only 25 firms.

On the other hand, the NSF's survey-based estimate of R&D funding underestimates automotive R&D funded by U.S. companies because projections are limited to firms in the narrow standard industrial classification (SIC) of the motor-vehicle industry in the United States, namely SIC 371. Thus, expenditures from other closely related industries, such as automotive stamping (SIC 3465), are not included in the NSF total. The U.S.$2.8 billion difference between the NSF estimate of $7.5 billion and the *BusinessWeek* estimate of $10.3 billion can largely be attributed to overseas expenditures by U.S. auto firms and R&D contracted out to ES firms and the like in the United States and elsewhere.

Reliable data on Canadian automotive R&D are at least as difficult to obtain as the U.S. data. To create Table 1, OSAT had to use Statistics Canada's *Industrial R&D Statistics, 1987*. Unfortunately, the publication does not list separately in-house R&D spending for the motor vehicle industry alone. Data in Table 1 in the automotive column were drawn from a category called "Other transportation equipment" (that is, transportation equipment that excludes Canadian aeronautics equipment).[52] Other estimates of automotive R&D do exist in Canada. Industry, Science and Technology Canada (ISTC) and some private sector organizations collect data. However, the interpretation of what should be included in ISTC's term "R&D" remains imprecise. No Canadian estimate of R&D would knowingly include any phase of "styling" vehicles, as according to OSAT, the NSF conceivably does. Moreover, R&D for "other transportation equipment" includes contributions from industries such as railroads and shipping.

Table 1. Industrial and automotive R&D (companies' own funds, $billions) and vehicle assemblies (millions of units): United States and Canada (1980-1989)

	U.S. (U.S.$)			Canada (C$)		
	Industrial R&D	Auto R&D	Vehicle assembly	Industrial R&D	Auto* R&D	Vehicle assembly
1980	$30.48	4.30	8.01	1.36	.045	1.38
1981	35.42	4.22	7.94	1.85	.062	1.28
1982	40.48	4.32	6.99	2.15	.066	1.24
1983	45.04	4.75	9.23	2.25	.079	1.50
1984	52.73	5.38	10.94	2.52	.077	1.84
1985	58.48	6.16	11.65	3.04	.086	1.93
1986	61.73	7.19	11.32	3.38	.097	1.86
1987	62.80	7.30	10.93	3.50	.093	1.64
1988	66.50	7.80	11.22	3.83	.091	1.98
1989	68.50	7.50	10.85	4.03	.093	1.94

Sources: National Science Foundation, *Science and Technology in U.S. Industry*, (NSF 88-321), and *Science Resources Studies Highlights*, (NSF 90-307) (Washington D.C.). Statistics Canada, Industrial R&D Statistics, 1987, (Cat. 88-202). *Ward's Automotive Yearbook*, 52nd Ed.. Wards Communications, Detroit, MI, ISBN 0-910589, 1990, p. 17.

* "Other Transport Equipment" (apart from aeronautics)

Despite the limitations, Table 1 depicts estimated levels of company-funded and -performed R&D for the U.S. and Canadian automotive industries. These figures may be compared with levels of total industrial spending (not federally funded) in the two countries between 1980 and 1989.

In current dollars, company funding of industrial R&D in the United States doubled during 1980-1989 — it actually tripled in Canada. During the same period, automotive R&D in the United States increased by only about 75 per cent. Most of this rise occurred in 1983-1986, a period of larger auto profits, heavy spending on automation, and some product development. Canadian automotive R&D actually doubled during 1980-1989, but remained relatively much smaller than U.S. levels of spending throughout the period. Moreover, any increase recorded in Canadian automotive R&D is probably attributable to auto parts firms as much as to assemblers.

Factors such as fluctuations in exchange rates and different levels of sectoral inflation will also affect interpretation of the table. For example, OSAT believes that Canadian automotive R&D grew by only about 50 per cent rather than the 100 per cent shown in Table 1. In any event, as revealed by the official figures, the Canadian R&D effort is quite low. Looking on the bright side, however, it is probably higher than indicated in the table and certainly appears to be improving.

The Canadian auto sector can be described as being dominated by many final-assembly plants, with a few captive component plants, and having only a relatively small, independent parts industry. The 1965 Auto Pact may have brought about this curious, trade-determined structure. Canada still imports many U.S. (and now Japanese and Korean) parts used in the final assembly of up to two million vehicles per year, most of which are destined for the United States. This pattern has produced large Canadian automotive trade surpluses with the United States in recent years. Canada's reliance on

billions of dollars of imported parts and components, however, makes the sales or shipments figure for the industry highly suspect in comparative analysis with other automotive industries. A value-added approach to comparing R&D for the expenditures in the United States and Canada appears more sensible than one based solely on sales. In 1986, the Canadian motor-vehicle and auto-parts industries shipped products worth about C$37.3 billion. Value added in the auto industry, however, amounted to only about $6.8 billion, or 18.5 per cent of the value of the shipments. Automotive R&D in 1987, according to the Automotive Directorate of ISTC, amounted to about C$92 million, or 1.35 per cent of value added.[53]

In 1986, the U.S. motor-vehicle industry (SIC 371) shipped products worth about U.S.$191.5 billion; much of this total represents double-counted sales between suppliers and OE shippers. The total value added by the industry, however, was U.S.$59.2 billion, or about 31 per cent of the value of gross shipments. U.S. automotive R&D in 1986, according to the NSF, was U.S.$7.2 billion, or about 12.2 per cent of the total value added.[54] The ratio of "value-added R&D intensities" in Canada and the United States was roughly 1.35/12.2 or about 11 per cent. This figure is very close to the Automotive Directorate's 10 per cent ratio and is probably more meaningful than a sales-based comparison. However, the conclusion remains that relative to value added, in Canada automotive R&D is very low compared with that in the United States, Japan, or Europe.

Compared with the relatively high R&D expenditures by the U.S. Big Three and the automotive sector in the rest of the world, the amount spent on automotive R&D in Canada has been remarkably low. Total spending on automotive R&D in Canada equalled approximately C$92 million in 1987: approximately $41 million by assemblers and $52 million by parts producers. The $41 million spent by assemblers represents a small percentage of their sales in Canada, whether calculated on a sales or a value-added basis.

The low level of Canadian spending on automotive R&D follows a pattern of low Canadian spending in industrial R&D overall. In 1989, industrial R&D spending in the United States exceeded Canadian levels (in U.S.$) by a factor of almost 20 to one. In the United States, the motor-vehicle industry alone, indeed just GM, spent more on industrial R&D in 1989 than did the entire Canadian economy — and, as we have already seen, the Japanese industry in turn may well be overtaking the U.S. one.

By virtually any measure, automotive R&D in Canada has been minimal. For example, research expenditures as a percentage of sales are among the lowest of any industry in Canada, at 0.3 per cent. In medium-intensity sectors, such as business machines, the percentage is 3.5 per cent and in high-intensity sectors, such as telecommunications and aerospace, R&D accounts for 18 and 14 per cent respectively. In contrast, in 1980, the Organization for Economic Co-operation and Development (OECD) reported a research intensity of 3 per cent in the U.S. automotive industry, 2.3 per cent in the Japanese, and 3.2 per cent in the German.[55] The R&D intensity for the Canadian auto industry is about 10 per cent of U.S. levels — the worst performance of any major industry in Canada.[56] To match the average OECD level of R&D intensity, Canada would have to spend an additional billion dollars.[57]

The automotive industry also ranks near the bottom of Canadian manufacturing industries for absolute R&D expenditures. Expenditures of C$92 million in 1987 were surpassed by expenditures in telecommunications ($831 million), aerospace ($501 million), business machines ($330 million), electronics ($305 million), chemicals ($202 million), petroleum ($142 million), drugs ($127 million), and nonferrous metals ($104 million). Furthermore, in 1984 the OECD reported official R&D expenditures in the automotive sector of U.S.$4.8 billion in the United States, U.S.$2.7 billion in Japan, and U.S.$3.2 billion in Europe, for a total of more than $10 billion.[58]

In contrast to generating much wealth and employment, the automotive sector is one of Canada's largest underperformers of R&D. Because assemblers centred in the United States and, more

recently, in Japan dominated automotive engineering, the development of automotive technology in Canada has been minimal. Neither U.S.-based nor other foreign-based assemblers have chosen to perform major R&D in Canada.

Canada's effort in total industrial R&D would improve markedly if the nation's automotive assemblers attempted to meet the R&D/sales ratios of their U.S. counterparts. In 1987, for example, Canadian assemblers spent C$40 million on R&D and enjoyed sales of 22.4 billion — a R&D/sales ratio of less than one-fifth of 1 per cent. To achieve a R&D/sales ratio similar to that of the U.S. assemblers and a ratio appropriate for its ranking in the Canadian economy, the industry needed to spend an additional C$630 million on R&D. The effect on both total industrial R&D and Canada's GERD/GNP would have been profound. Industrial R&D would have totalled C$4.7 billion — 15 per cent higher than the actual figure. Canada's GERD/GDP ratio would have reached 1.49 per cent rather than 1.37 per cent.

The minimal R&D that the Canadian automotive sector does perform is generally "adopt and adapt." Assemblers maintain small engineering staffs in Canada. These people primarily test vehicles for cold weather conditions and adapt vehicle designs to meet Canadian regulations. Both assembly and parts producers concentrate on process engineering. The Canadian automotive sector acquires its technology mainly from equipment suppliers. It has little or no interaction with universities, government laboratories, or technical centres. This severely limits the sector's ability to conduct truly innovative research.[59] The sector should take advantage of Canada's advanced skills and motivation to improve the sector's competitiveness.

It is alarming that Canada gains so little in terms of R&D and development of engineering skills from so vital an industry. New technologies, supported by superior management techniques, are important driving forces behind the Japanese success. The Big Three must match **both** new technologies and superior management to survive and prosper.

Challenges and Opportunities for the Canadian Automotive Sector

Can Canada involve itself in more intensive R&D in the future? Canada's prospects, at least initially, seem better with the Big Three than with offshore-based assemblers.

Although Canada performs little of its own R&D, it has benefited from technology transfer from foreign sources. Several key indices show that Canada makes good use of the foreign technology available. Because of this, productivity growth in the automotive sector surpassed that of the United States during the 1980s. It has also surpassed the average growth in Canadian manufacturing. Investment in and adoption of technologies such as statistical process control (SPC) and computer-aided manufacturing (CAM) have increased rapidly.[60]

Technology transfer has been a successful strategy, but it is now not enough. Japan has led the push for increased technological sophistication, changing the competitive environment. Japanese firms also benefit hugely from their suppliers' R&D in their tiered production. Can the Big Three really afford to ignore such fundamental shifts?

These changes both threaten and create opportunities for the Canadian automotive sector. As the sector becomes technologically intensive, and the parts sector becomes tiered, Canada risks losing its share of high value-added jobs. With increased emphasis on product and process engineering, both assembly and parts plants must provide, at the very least, process-engineering skills. Failure to do so will lead to an attrition of basic manufacturing capability: assemblers will prefer to source from a low-wage country unless sizable value is added on.

Already there are changes in the technical activities in Canada. Genuinely innovative R&D is emerging. This R&D represents important "niche-engineering" projects. At GM Canada, the Oshawa expansion included a new Technical Centre focusing on innovations. GM Canada, for example, is developing its 3800 engine for the Buick Regal. Ford is researching alternative fuels, especially methanol. Results so far are interesting. Ford has confirmed methanol's generally positive performance benefits (e.g., improved acceleration), and has also developed sensors for car engines that trigger automatic adjustment for different types of fuel (for example, different blends of gasoline and alcohol). This is R&D capitalizing on specific Canadian conditions or resources — in this case, Canada's large quantities of natural gas, which could be turned into methanol.

Why have the Big Three and not the transplants initiated this sort of research in Canada? The Big Three are on the defensive. They must search out opportunities to compete against the offshore nameplates. That may require increased decentralization and contracting out.

The offshore nameplates are also decentralizing. Mazda, for example, had its highly successful Miata sports car designed in California. This is an example of developing a new product in a most demanding customer area. Honda has designed and engineered new models at its Ohio complex (for example, the new Accord station wagon). Mazda and Honda, too, are searching out talent anywhere they can find it.

A spectacular example of a successful contractor is Italdesign of Italy. Formed by an immensely talented designer, Georgetto Guigiaro, Italdesign employs stylists and engineers from all over the world. On contract, it has successfully designed vehicles ranging from the Korean Hyundai Excel, an economy subcompact, to the British Lotus Esprit, an exotic sports car.

Another factor that might favour Canada in automotive R&D is any lack of skilled labour in the United States. At present, the United States has the most employed engineers, natural scientists, and related technicians in the world. No fewer than 2.45 million engineers and natural scientists were employed in 1988. An additional 1.27 million engineering and science technicians and technologists

could be added to this figure, giving a total of 3.73 million scientific and engineering personnel.[61] This total does not exclude almost 101 500 natural scientists and engineers with PhDs who were teaching in universities and colleges, nor does it include 173 000 graduate students in these fields in 1988.[62] A perhaps inflated figure for similarly educated Canadian scientists, engineers, technicians, and technologists was 433 000 in 1988.[63]

The U.S. Department of Labour (USDOL) in 1988 reported that engineers represented about 4.3 per cent of total employment in the U.S. motor-vehicle industry (SIC 371); in absolute terms, this is roughly 37 000 engineers. About half of these were mechanical engineers; the rest were electrical, material-science, and industrial engineers. To this figure can be added 27 000 natural scientists, computer programmers, and engineering and science technicians. Together these occupations constitute about 7.4 per cent of total employment in the industry. This is not an especially high proportion for the science and engineering fields, particularly when compared with the percentages in the aerospace and electrical equipment industries.[64]

The NSF surveys the number of full-time or equivalent scientists, engineers, and related technicians engaged solely in industrial R&D. In 1987, for example, the NSF estimated that the U.S. motor-vehicle industry employed 50 600 natural sciences and engineers in full-time R&D.[65] This represents an all-time record for such employment: it is almost twice the level estimated for 1978. Yet the NSF's measurement differs notably from that of the USDOL. NSF results indicate that a remarkable 79 per cent of all engineering and science personnel in the industry are fully involved in R&D activities. In fact, the 1987 NSF figure for R&D employment is a serious overestimate. The NSF permitted one of the large responding firms (GM) to include employment of scientists and engineers at two newly acquired nonautomotive firms (Hughes Aircraft and Electronic Data Systems). R&D activities at these two subsidiary firms are so general that even the NSF's overall post-1985 estimates of U.S. spending in automotive R&D must be considered doubtful.[66]

The 1985 NSF total of 28 700 may be the most reliable recent estimate of R&D employment in the U.S. auto-vehicle industry. This figure represents a major decline from the 1980 peak total of 38 200. This reduction is indirectly supported by anecdotal information about reductions in engineering staffs at the Big Three. It is directly supported by increases in R&D contracted to ES firms. The NSF also reports that in 1985 the U.S. auto-vehicle industry employed 28 engineering and science R&D personnel per one-thousand industry employees. The ratio makes sense: in conjunction with the 28 700 figure cited above, it results in a total employment of about 804 000. This corresponds reasonably well to the USDOL estimate of 883 000. This decline in R&D employment in the U.S. automotive industry, at a time of increasing technological demands throughout the sector, suggests opportunities may exist for Canadian firms and personnel to fill the emerging gap.

The most outstanding feature of R&D employment in the U.S. motor-vehicle industry, as reported by the NSF, is the total expenditure per engineer and scientist employed. One computes this statistic by dividing total expenditures in industry R&D by total employment in industry R&D. In 1985, this resulted in U.S.$224 700 per R&D worker in the motor-vehicle industry, 64 per cent more than the U.S. industry average of $137 000.[67] R&D cost per worker in the motor-vehicle industry has always been the highest of any industry studied by the NSF, and this difference has increased in recent years. Because the NSF estimate of R&D expenditures excludes the funding of non-U.S. R&D and contracted R&D, the higher per-employee cost of motor-vehicle R&D can result only from higher salaries or the use of more expensive R&D plants and equipment. There is evidence that both reasons have applied in recent years, especially when the cost of CAD/CAM and CAD/CAE equipment is counted. If this is the case, then decisions on locating R&D facilities must take into account the costs of capital, income taxes, and the ease of acquiring equipment from outside the location.

One can use the NSF data in conjunction with recent data on employment in the Canadian automotive industry to estimate potential Canadian automotive R&D. In 1986, 118 200 Canadians

manufactured motor vehicles and automotive parts.[68] The U.S. ratio of 28 engineering and science R&D personnel per thousand industry employees suggests a potential Canadian automotive R&D employment total of 4 221. In turn, one can use this number with the R&D costs of $224 700 per employee to estimate a potential of U.S.$948.6 million for Canadian spending on automotive R&D. This is roughly 10 times the amount actually reported in Canada for 1986. This level of R&D spending would have constituted 2.5 per cent of the dollar value of Canada's total automotive shipments in 1986 and yet remain less than the U.S. ratio of 3.8 per cent.

In early 1990, GM announced a six-month program to cut costs by U.S.$1 billion. This program included reductions in advertising, outside consulting, new tooling, engineering materials, travel, and product development. As well, the merit increases for salaried employees were delayed. Many types of hiring were also suspended. One exception was made, however; nearly 1500 new college graduates, especially recently graduated engineers, were hired. Although the corporation had almost countless expenses and programs where cuts could be made, it went ahead with hiring technical labour. This shows that an adequate supply of technical labour remains a priority in the U.S. motor-vehicle industry.

There have been some recent concerns in the United States about the adequacy of the labour supply in science and particularly engineering. In 1986, U.S. colleges and universities granted 213 971 Bachelor's degrees in natural science and engineering, more than the 175 395 for France, West Germany, Japan, and the United Kingdom combined. Yet only 77 061 of the U.S. degrees (36 per cent) were awarded in engineering, a figure that is comparable only to the 1985 Japanese graduation of 73 316 engineers (74 per cent of the 99 668 1985 science and engineering graduates). A related and equally striking statistic is that in Japan, engineering degrees were earned by no less than 4.4 per cent of their 22-year-old population, compared with 1.9 per cent for the United States.[69]

However, there were many more PhD's in engineering and natural sciences in the United States than in Japan: in 1986, 12 974 doctorates were granted compared with 2961 in Japan. The gap in the numbers of new engineering doctorates was smaller: the United States had 3376; Japan had 1404. Although the United States appeared to maintain a comfortable two-to-one advantage in supply, more than half of the new engineering doctorates in the United States were granted to foreign students. This represents a startling turnaround in terms of potential competitiveness.[70]

As opposed to graduate engineers, a final observation should be made regarding the demand for, and the supply of, engineering and science technicians. Even in late 1990, the USDOL had yet to define or track a new engineering technician occupation that used computers to design and test products or to program electronics in durable goods such as motor vehicles. "Drafters," or those in drafting occupations, is an archaic definition still used for labour projections in this field. As a result, little is known about the present or future employment of these new technicians. Their training and supply also remain unstudied. Anecdotal evidence clearly indicates the importance of such staff in R&D in the motor-vehicle industry. Recent difficulties in finding employees with these new skills support this assertion. Any skills shortage within the United States means potential opportunities for Canada.

There are at least three major opportunities for future automotive-vehicle R&D in Canada:

- contract engineering;
- specialized equipment (for examples, alternative fuels and fuel systems); and
- specialized platforms (for examples, further development Canadian-produced platforms or development of entirely new ones).

Contract engineering, in this context, refers to the out-sourcing of design and R&D. If an outside firm can offer major gains in speed combined with manufacturing practicality, Detroit has a powerful incentive to use such services.

"Niche" specializations offer another possibility for contract engineering. Already some Canadian firms are independently developing unique products. For example, the Prototype Research and Development Company in Campbellford, Ontario, specializes in fibreglass bodies customized for proprietary chassis. Although this has been attempted before in Canada and the United States, the Prototype Reseach and Development Company is determined to take advantage of the latest technological advances in materials, moulds, paint, and finishing techniques. There may be good prospects for growth in this type of business.

Specialized equipment refers to automotive products, whose research could logically be done in Canada because of unique Canadian circumstances that favour development here. An obvious example is alternative fuels. Ford, in cooperation with Shell Canada, has a fairly substantial R&D program in Canada to investigate methanol as a substitute for gasoline. Canada could produce methanol relatively cheaply from its reserves of natural gas. Results so far are promising. Because cold-start problems have been encountered, for example, Canada is an ideal location to look for their solutions. It is noteworthy that methanol produces different emissions from gasoline. It generates much less photo-chemical smog, the chief element of air pollution in Los Angeles. The California state government has even introduced legislation requiring that 10 per cent of all new vehicles be powered by such alternative fuels. This offers more R&D opportunities to Canada. The potential for R&D in electric-vehicle technology is similarly attractive.

Canada already has some firms that could do R&D in material sciences for the automotive sector. With Japanese firms seemingly ahead in steel and materials research (see Science Council Sectoral of Canada Technology Strategy Series, No. 3: *The Canadian Iron and Steel Sector*), Detroit may be hurt. This suggests the need for cooperation between Canada and the United States.

Specialized platforms could involve major redesigns of cars, or perhaps decentralizing an assemblers' R&D function, physically moving it closer to individual manufacturing plants. From a lean-manufacturing point of view, if the R&D function were closely integrated into product development and continual process improvement, it could make sense to relocate R&D.

Canadian assembly plants have tended to be very stable in their product lines. Examples are Ford's Crown Victoria-Mercury Grand Marquis at its St. Thomas, Ontario, plant; Chrysler's Minivans in Windsor; and GM's Camaro-Firebird line in Ste-Thérèse, Quebec. In an age of lean manufacturing and just-in-time delivery, R&D should be decentralized to a certain extent in those product lines. The Big Three have centralized R&D in in-house laboratories. Were they wise in pursuing this strategy? The evidence suggests that decentralization of Japan's R&D has given that country a competitive edge.

Lastly, consider entirely new vehicles or platforms. Must North America follow the Japanese in defining the evolution of automotive products? An entirely new platform might be suitable for, say, former Communist countries or developing countries. It would probably not need as many of the features North American and Japanese consumers demand. An easy-to-maintain or easy-to-repair vehicle might be more suitable. Although the idea of a "Model A" Ford for the 1990s may seem fanciful, conditions in evolving markets may require a different approach. Detroit could conceivably look to fresh overseas investment that capitalized on different designs. Would Japanese firms be vulnerable — locked into a product mix and complex automated process technology that might not do as well in the field as simpler, more appropriate technology?

The experiences of Western computer firms provide some useful insights for automotive firms thinking of expanding into markets in the former Eastern bloc. Until recently, high-technology companies concentrated on providing the Soviet government with costly, advanced computing equipment. Given the high cost of such devices and the nature of Soviet bureaucracy, penetrating this market has been slow and orders have been small. Suppliers are ignoring the huge potential demand for "low-tech" items such as basic calculators and simple personal computers.[71] While firms have been pushing for the removal of export controls on advanced devices, Soviet citizens and businesses

continue to rely on the abacus and pen and paper. The key to this vast potential market for basic machines is appropriate technology. Reliability, simplicity, and economy will be requisite characteristics of successful products. Interestingly, Soviets need some mechanical knowledge before they are issued with their driving licences. So, among the existing drivers may be a large potential market for home maintenance of their vehicles. This implies a very different vehicle design than that typical of the North American market today. The eventual size of the market worldwide is incomparably larger than the U.S. or Japanese, if it can be developed wisely.

This strategy is the one favoured by the Italian automaker, Fiat. The company's products are not well represented in North America, but that has not stopped the firm from becoming a global automotive assembler. It has focused its development and marketing efforts on relatively new markets. For example, it established a Spanish subsidiary, SEAT. This was a shrewd investment, for it allowed Fiat to benefit from the rapid post-Franco industrialization of Spain in the 1970s. Fiat has also established a presence in Greece, South America, North Africa, the USSR, and even India. Fiat cars may not have been ideal for North American conditions, but North America is not the only market. No doubt Fiat will increasingly feel pressure from the efficient Japanese producers as the latter expand their production and marketing efforts. But options do exist for an innovative business strategy, backed up by a novel product mix and marketing philosophy. Can Canada provide a congenial working environment in which to explore these alternatives? Should the Canadian subsidiaries of the Big Three be involved in this R&D and design for an easy-to-maintain and -repair vehicle for developing countries and other less demanding markets?

Canadian talent would be ideal for such new product development. Both Canada and Detroit might gain by such innovative strategies.

A major consideration in the development of Canadian automotive R&D is skilled labour. No other area of automotive manufacturing requires a higher average level of skilled labour than R&D. Vehicle producers must encourage an adequate supply of trained and trainable R&D personnel to maintain and improve their products and processes. Above all, this applies to CAD functions. Recent escalating costs of R&D plants and equipment emphasize the importance of the labour assigned to work with R&D physical capital. The costs of employing such labour and acquiring such capital are critical to determine the allocation of R&D funds. Canada would need to upgrade the technical skills of its R&D staff, but the potential to capitalize on our highly qualified personnel remains.

Canada will clearly not be a leader in technological innovations shaping the global automotive industry. The roles for the Canadian assembly sector depend entirely on decisions made by American and Japanese assemblers. Both Canadian assemblers and parts producers face barriers to increasing their levels of R&D that are rooted in their past low levels of this activity. This has resulted in an inadequate pool of trained personnel, lack of facilities, and a preference of the Big Three to centralize R&D in the parent company.

Conclusion

Worldwide, the automotive industry is undergoing a fundamental transformation. This is not just a series of small, disjointed, random changes. Rather, it is a host of major, interrelated changes in management philosophy, assembler-supplier relationships, distribution-maintenance services, and engineering-development systems. In short, the auto industry is converting from mass-production to lean production and, ultimately, to the lean enterprise.

This transformation in production process will no doubt have implications not just for the auto industry but for virtually all industrial sectors. According to the authors of MIT's comprehensive study of lean production in the world auto industry, "We've become convinced that the principles of lean production can be applied equally in every industry across the globe and that the conversion to lean production will have a profound effect on human society — it will truly change the world."[72]

In simple terms, there are only two ways for lean production in the auto industry to diffuse across the world. The Japanese lean producers can spread it by building plants and taking over companies abroad, or the American and European mass-producers can adopt it on their own.

During the 1980s, Japanese automakers used their leadership in lean production and its competitive advantages to capture increasing market shares from their American and European rivals. As we enter the 1990s, it is clear that the Japanese auto-makers are widening this gap. They are active in every segment of the vehicle market and are poised to challenge Detroit's large cars and light-weight trucks — the two remaining profit and volume strongholds of domestic automakers. The Japanese have successfully transferred their manufacturing know-how to North America without sacrificing productivity or quality. In the process, they have groomed a generation of managers who can confidently continue their global strategy. Moreover, their design and engineering operations in Japan, Europe, and the United States have responded to the needs and desires of customers in specific markets. And their rapid process of product development allows them to incorporate new technical features quickly.[73]

Lean production is the benchmark by which the North American automotive industry must measure itself. Regardless of the origins of the nameplates, the skill level and technology must be there. Moreover, innovations in both products and marketing will still come from this industry.

The issues for Canada are whether we will have anything new to offer and whether the evolving structure of the industry will accept it if we do. But it is in the interests of global automotive firms to use creative ideas from anywhere they can find them.

Appendix: Framework for Technology Strategies

As part of the methodology for analysing each sector, the Science Council of Canada sought whenever possible to assess company technology strategies according to the following framework:

	adopt and adapt	innovation	breakthrough
product			
process			

Strategy Classes

Adopt and Adapt: Acquire a technology and adapt it to serve as a competitive platform.

Innovation: Incrementally improve on winning technology to get greater market share or maintain competitive edge.

Breakthrough: Seek to create a discontinuity in the marketplace, thereby leaping ahead of the competition.

The company case studies generally looked for at least seven key dynamics influencing a company's technology strategy:

- three internal dynamics:
  - competitive position,
  - capacity for innovation, and
  - strategy and vision; and
- four external dynamics:
  - customer demands,
  - competitive rivalry,
  - supply condition, and
  - available technology.

The methodology also incorporated essentially a three-step process for each sector. In the first step one or more contractors analysed the main elements in the competitive and R&D performance of the Canadian sector and its leading foreign competitors. The second step included evaluation of the contract report(s), discussion with contractors and other experts, additional in-house research, and preparation of a draft Council report. In the third step, external reviewers commented on one or more drafts of the Council report, which were then revised and refined as required, drawing on the advice of the liaison person for that sector on the Steering Committee (see Acknowledgements). For some sectors, the third step also involved several external reviewers in a small workshop, one part of which

helped define some elements of a potential action plan for the sector. The report was then submitted for final approval to the Executive Committee of the Science Council, before being forwarded to Industry, Science and Technology Canada.

Notes

1. J.A. Casesa, quoted in Paul Ingrassia, "Losing control: Auto Industry in U.S. is Sliding Relentlessly into Japanese Hands," *Wall Street Journal*, 16 February 1990, 1.

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35. Ibid., 155.

36. Ibid., 168.

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42. Automotive Directorate, Industry, Science and Technology Canada, op. cit., p. 11.

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50. "Innovation: The Global Race," *BusinessWeek* (15 June 1990), 197-198.

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